Empirical Features of Weaving Sections

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Abstract:
A motorway weaving section is a segment of the road in which an on-ramp is followed by an off-ramp with limited spacing between them. Various equations have been adopted to determine the capacity of such weaving sections. Some of these include factors such as weaving ratio (R), volume ratio (VR) and weaving configuration, all of which influence the weaving capacity. For this paper, drivers' behaviours at weaving sections were studied in order to assess the effect on capacity of such sections and to aid in the development of a micro-simulation model to evaluate the performance of these sections for various configurations. Factors such as VR, R, the upstream traffic characteristics, the frequency of lane changes (FLC), the percentage of the pre-segregation for the upstream traffic of weaving section, the length of weaving section and a merging point were investigated. For this purpose seven weaving sites with different configurations and lengths were selected. The results of the analysed data indicated that the FLC differed according to the configuration of the weaving section. For example, in the case of ramp weaving sections (i.e. lane gain/lane drop), the results indicated that the maximum FLC in every 76 metres (i.e. equivalent to 250 feet) within the weaving section is up to 1500 per hour. This value was found to be much higher than those reported in other studies. In addition, the effective length that was used by those weaving vehicles was also influenced by the type of weaving configuration. For short weaving sections (i.e. 150 metres or less) the effective length is basically the whole length, whereas, for relatively longer weaving sections (i.e. 300 metres or more), the effective length is found to be equal to 200 metres or less.

Keywords:

Weaving capacity, weaving length, weaving ratio, merging point

1 Introduction

The efficiency of motorway performance is mainly affected by the capacity of weaving sections which are normally associated with traffic disturbance due to a relatively high intensity of lane changing manoeuvres. Kwon et al., (2000) reported that in order to develop the effective operational strategies for motorway management, there is a need to understand the behaviour of weaving traffic and estimate the effects of variations in traffic conditions with time. They found that under moderate to heavy flow conditions, lane changing activities tend to concentrate close to the start of the weaving section.

Recently, Lee and Cassidy(2009) reported that field data collected from weaving sections suffered from lacking comprehensive information such as this speed under congestion or non-congestion condition and after bottleneck or before bottleneck.

In light of the above, this study has been conducted to examine the effect of different factors such as VR, R, and traffic segregation under certain conditions. In addition, an overview of weaving types (with relevant definitions) has been shown. Factors affecting weaving capacity were discussed and the results obtained from observations have been presented.

2 Weaving section

The Highway Capacity Manual (HCM, 2000) classifies weaving sections into three types: A, B and C according to the minimum number of lane changes applied by weaving vehicles. Figure 1 shows typical weaving sections for two of these types, namely A and C, which are commonly used in practice. Further details of the various configurations can be found in the HCM, 2000. The main difference between type A and other types is the existence of a crown line which connects the entrance (nose) with the exit (gore) sections.

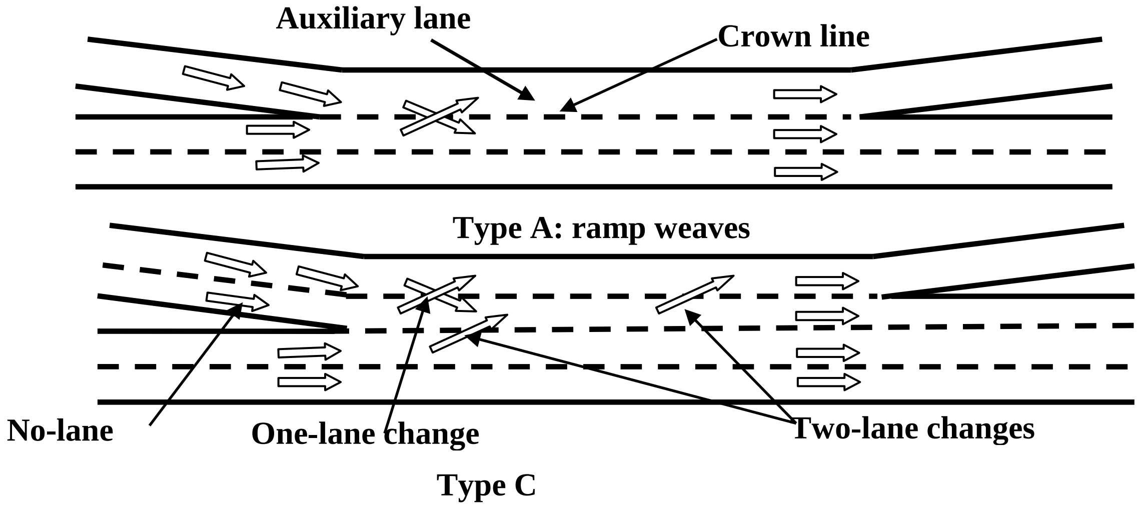


Figure 1 Selected weaving section types (HCM 2000).

2.1 Definition of weaving capacity

According to the HCM (2000), capacity of weaving sections can be defined as the maximum total weaving flow beyond which acceptable operations are unlikely to occur. The HCM provides the thresholds of density which are associated with estimated speeds of the weaving and non-weaving traffic. However, it does not include any explicit procedure for the estimation of the maximum weaving flow under different geometric designs and traffic conditions.

Cassidy and May (1991) defined weaving capacity under two conditions. Firstly, the maximum flow of vehicles per lane at any point of roadway within a subject weaving area is 2200 cars/hr/lane. Secondly, the maximum rate of lane changes (between two adjacent lanes) that can occur over any 76-m segment within the weaving area is 1100 to 1200 lane changes per hour, across a single line-lane.

2.2 Factors affecting weaving capacity

Several factors have proved to affect the capacity of weaving sections. These include, type of weaving section, volume ratio, weaving ratio, length and width of a weaving section, weaving and non-weaving speeds (Lertworawanich and Elefteriadou, 2003).

2.2.1 Volume ratio (VR)

Volume ratio can be defined as the weaving volume (V_w) divided by the total volume (V) entering a weaving section (HCM 2000). It can be calculated as shown in the following equations (see also Figure 2):

$VR = V_w / V$ ....Equation 1

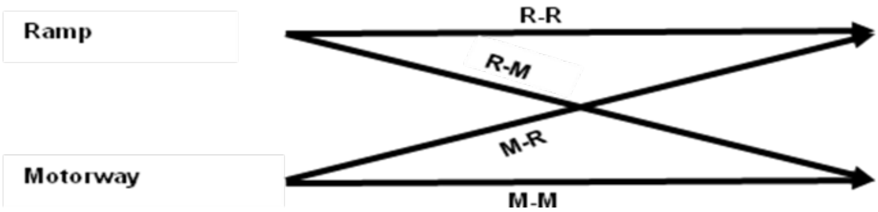
$V_w = W_1 + W_2$…...Equation 2

Where;

W_1: represents the small weaving flow, and

W_2: represents the large weaving flow.

The HCM (2000) recommended that for type A, the value for VR should not exceed 0.45 and 0.35 for three and four lanes, respectively, whereas for Type C it should not exceed 0.5. Generally, as volume ratios increase under high flows, for all weaving types, the turbulence increases.



R-R is ramp to ramp flow (non-weaving flow)

R-M (either W_1 or W_2) is ramp to motorway flow (weaving flow), also called merging traffic

M-M is motorway to motorway flow (non-weaving)

M-R (either W_1 or W_2) is motorway to ramp flow (weaving flow), also called diverging traffic

Figure 2 Details of weaving movements.

2.2.2 Weaving ratio (R)

The weaving ratio represents the proportion of small weaving volume from one direction to the total weaving (HCM 2000), as shown in Equation (3). If this value equals to zero (i.e. if W_1=0), this means that the section operates either as an isolated merge or as an isolated diverge section. The maximum value for R is equal to 0.5 at which the section operates at high turbulence (i.e. due to increased interactions between vehicles). This normally exists when flows are at/or approaching capacity (Fazio and Rouphail, 1990).

$R = W_1 / V_w$ ....Equation 3

2.2.3 Driver behaviour and weaving bottleneck

The operation of the motorway is affected by congestion within the weaving area when traffic demand exceeds the capacity of the weaving section. Traffic operational problems may also exist at this section even when traffic demand is less than its capacity because of the complexity of vehicle interactions (Skabardonis and Kim, 2010).

Lee and Cassidy (2009) reported that drivers' behaviour is an important factor in determining the capacity of weaving sections. They also indicated that most studies might not reflect the actual behaviour of weaving sections because they did not attempt to use real traffic data to explore the reasons behind bottleneck activation. Bertini and Malik (2004) noted that bottleneck activation was accompanied by flow discharge reduction. They hypothesised that bottleneck was triggered by vehicular conflicts between merging and diverging traffic when on-ramp flows increased. They also observed that subsequent reductions in on-ramp flow consistently coincided with bottleneck activations, and speculated that these reductions in on-ramp flows were constrained by queues on the motorway caused by those diverging drivers.

The study by Lee and Cassidy (2009) used the same data of Bertini and Malik (2004) and revealed that on-ramp flows were only around 200 veh/hr immediately prior to the bottleneck activation. Such flows are considered to be too low to cause congestion. Therefore, they suggested that on-ramp reductions might have been caused by a reduction in on-ramp demand rather than by the queues formed on the main motorway section (which is different from Betrini and Malik's speculation).

2.2.4 Traffic segregation

Weaving capacity is also affected by the segregation behaviour in the upstream section before the nose. Traffic segregation here refers to the manner in which weaving vehicles segregate from through traffic and relocate to the lanes closer to the auxiliary lane before entering a weaving section (Cassidy, 1990). A few studies tried to link traffic segregation with weaving characteristics. Pignataro *et al.* (1975) found that nearly 98% of motorway to ramp traffic relocates to the lane adjacent to the auxiliary lane before entering a ramp weaving section. In the same way, 60 to 85% of motorway to motorway traffic change lanes before entering a ramp-weave section in order not to be impeded by weaving vehicles.

Kojima *et al.* (1995) developed a simulation model to analyse the behaviour of drivers for type A weaving section. Field data were used to calibrate the model and two strategies for traffic behaviour at the upstream section, one "with controls" and the other "without controls" were applied in the simulation model. The "with controls" could, for example, represent the use of traffic signs to direct drivers to get onto the correct lane depending on their destinations before entering the weaving section. Although, the study suggested that in the case of "with control" showed that driver's behaviour is smoother than the case of "without control" (which initially seemed logical), closer look at the results that they obtained from simulation revealed that the differences in behaviour were not that significant.

2.2.5 Weaving length

A certain amount of space is required to conduct a lane changing manoeuvre. Vermijs and Schuurman (1994) when studying Type A ramp weave, found that most of the lane changes took place within the first 350m from the merge gore area of the weaving section. This suggests some discrepancy in the required weaving length used in design. In the UK, the Design Manual for Roads and Bridges (2010) determines the weaving length based on weaving volume (flow), total volume and design speed.

3 Research methodology

The research methodology consists mainly of collecting data from different sites within the Greater Manchester area. Then, from these data behaviour of weaving vehicles at

upstream of weaving sections and within weaving section have been investigated to be used in developing a micro-simulation model as a future work by the author.
Data has been collected using video camera and Motorway Incident Detection and Automated Signalling (or MIDAS). Using video camera has advantages in collecting some characteristics such as the cooperative and yielding behaviour. However, it has disadvantages in some characteristics such as gaps, relative speed and frequency of lane changes. These disadvantages belong to the consuming time and the degree of required accuracy.

3.1 Selection of sites

Seven sites of weaving sections have been selected within the Greater Manchester Area as indicated in Table 1. The criteria for selecting these sites are:

- Covering a range of weaving layouts.
- Having a range of traffic flow conditions.
- Having a suitable vantage point close to the weaving sections (such as an over-bridge or multi-storey building).

Table 1 Details of the visits for weaving section sites.

Section	Location	Description
Mancunian Way Site 1.	At the Eastern part of the Mancunian Way near Manchester Metropolitan University (MMU).	A total of 28 hours covering different periods during the day and for different days/months.
Mancunian Way Site 2- Section 1.	At the western part of the Mancunian Way.	4 hrs for evening peak
Mancunian Way Site 2 – Section 2.	At the western part of the Mancunian Way	5 hrs for evening peak
Northenden (A5108)-section 1	Within Northenden City.	2 hrs for morning / evening peaks.
Northenden (A5108)-section 2	Within Northenden City.	2 hrs for morning / evening peaks.
M60 –section 1	Between Junctions 2 and 3	4 hrs for morning and 2 hrs evening peaks.
M60 –section 2	Between Junctions 2 and 3	7 hrs for morning and 5 hrs evening peaks.

WB: West Bound; NB: North Bound; EB: East Bound; SB: South Bound.

Details on the duration and number of visits for each site is as indicated in Table 1. Figure 3 presents sketches representing the different layouts used for each of the sites.

3.2 Data collection

A wide range of data collection methods was used to obtain information on speed, flow and density. In this study, video recordings were used to collected data from sites.

Two cameras were used to collect data from the Mancunian Way. The sixth floor of the Manchester Metropolitan University (MMU) was used as a vantage point. Whereas, for the M60 and Northenden sites the vantage point used was the pedestrian bridge immediately upstream and downstream of the weaving section. The camera was positioned such that the operation of the entire weaving section could be captured.

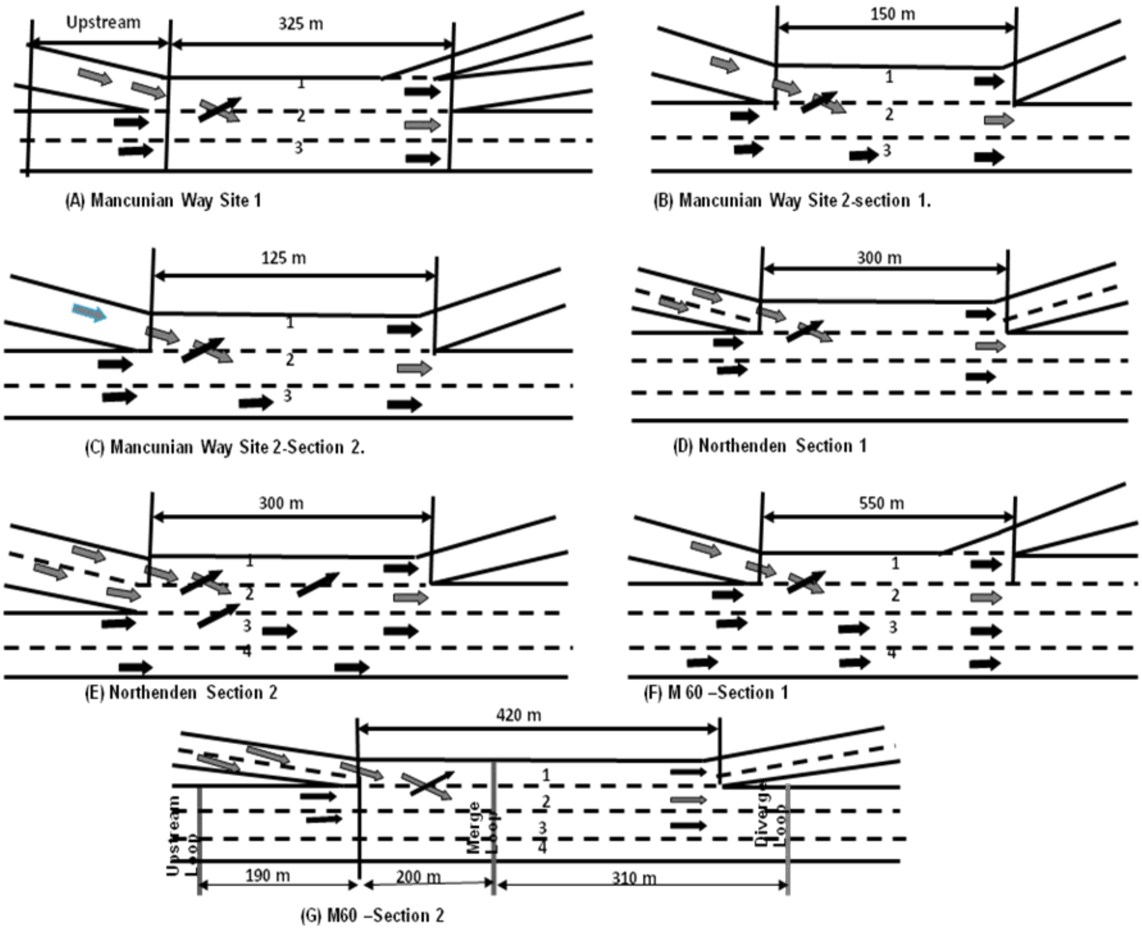


Figure 3 Weaving configurations for the selected sites.

3.3 Data extraction

The extracted data were on flow, vehicle classification and number of lane changes. The data was divided into 5-minute intervals. Video playbacks were shown on the computer monitor screen and a screen line was imposed to manually extract the necessary information using an event recorder (i.e. recording the time and counts when certain vehicles cross the screen line). The same procedure has been used to determine the location of merging points (i.e. when a vehicle is changing lanes by crossing the longitudinal pavement marking that separates the lanes).

The proportion of non-segregation behaviour for those weaving vehicles within the weaving section (i.e. after the nose) is calculated by dividing the number of vehicles changing lanes from any motorway lane (except the shoulder lane) by the total number of those diverging vehicles. While the proportion of non-segregation behaviour for those non-weaving vehicles is determined by dividing the number of vehicles staying in the shoulder lane and not changing lanes to the auxiliary lane (i.e. M-M as in Figure 2) by the total flow entering from the shoulder lane at the entrance point of the weaving section (after the nose). The length of each section has been determined using Google Earth as well as the standard distance between successive pavement markings as used in the Traffic Signs Manual (1985).

4 Finding and discussion

Different characteristics of weaving traffic were analysed and investigated through this study. These include flow rates, number of lane changes, upstream characteristics, merging points for both merging and diverging vehicles, weaving ratio and volume ratio.

4.1 Upstream characteristics

The proportion of weaving segregation vehicles (M-R) for Mancunian Site 1 is 95% and that for the Northenden Section 2 is 85%. The difference between these values could be attributed to the fact that for the Northenden site, the upstream distance between this section and the junction before it is only 350m, whereas that for the Mancunian Way Site 1 is about 900m.
For the Mancunian Way site, the average proportion of weaving vehicles segregating within the 250m upstream section from the diverging vehicles was 70%, while that for the Northenden site was 75%. Whereas, the proportion of non-weaving vehicles (i.e. M-M) in the shoulder lane which stayed in the same lane after entering the weaving section of the Mancunian Way Site 1 ranges between 40% and 60%. These proportions are lower than 60% to 80% as reported by Pignataro *et al.* (1975).

4.2 Weaving Section Characteristics

Characteristics for weaving section starting from entrance points and ending at exit points have been investigated as discussed in the following sub-sections.

4.2.1 Frequency of Lane Changes (FLC)

The lane changing (LC) manoeuvres implemented by the weaving vehicles produce frictions and turbulences that are not usually experienced on normal sections (Zarean and Nemeth, 1988). As the frequency of lane changes increases, the turbulence within weaving section increases and capacity decreases (Cassidy and May, 1991). Therefore, the frequency of lane changes was investigated from seven sites.

In a study by Cassidy and May (1991), the maximum number of lane changes between lanes 1 and 2 for a weaving section of 250 feet (equivalent to 76m) was 200 LC/hr. A similar length of weaving section of 76m was used for the Mancunia Way Site 1 and the results obtained showed a higher value of 1500 LC/hr. As flow increases, the concentration of lane changes becomes close to the entrance point which leads to the forming of platoons of vehicles. The speeds of these vehicles reach zero and queues start to build up.

Furthermore, Fredericksen and Michael (1994) used the FLC per hour per km as indictor to show the performance of non-motorway weaving section, unconstrained (<1863), constrained (1863-3726), and undesirable (>3726).

Table 2 FLC with different ranges of flow for some weaving sites.

Section	Maximum FLC LC/hr/km	Maximum FLC LC/hr/length of section	Range of flow veh/hr
Mancunian Way Site 1	**4615**	**1500 per 100m**	**1100-4050**
Mancunian Way Site 2-Section 1	**10800**	**1620 per 150m**	**2000-3500**
Mancunian Way Site 2-Section 2	**4800**	**600 per 125m**	**2000-3000**
Northenden Site 1	**7720**	**2316 per 300m**	**2900-5000**
Northenden Site 2	**8333**	**2450 per 300m**	**4000-5600**
M60 J 2 Site 1	**3600**	**1800 per 500m**	**5000-8000**
M60 J 2 Site 2	**5171**	**2172 per 420m**	**4200-7260**

The Mancunian Way Site 2 Section 1 could represent a case of a non-motorway weaving section due to the relatively lower speed limits used (i.e. 50mph) and the close proximity of several intersections within a relatively short distance. Although the frequency of LC in this site exceeds the undesirable conditions reported by Fredericksen and Michael (1994), observations suggest that traffic operation could still be considered as desirable. Therefore, the criteria used by these authors might not be considered as an effective tool to describe the operational performance of traffic within the weaving section. This could be attributed to the initial length (weaving length) used in calculating the equivalent frequency of lane changes per km.

4.2.3 Volume and weaving ratios

The observed values of VR and R for all seven sections are shown in Table 3. The Table shows the range of flow for each section, the maximum value for VR with the corresponding flow and the maximum and minimum value of R with the corresponding flow for each case. The Mancunian Way Site 1 and Northenden Section 2 gave the highest value of VR among other sections due to high interaction between weaving and non-weaving flows. The VR value for the M60 Sections 1 and 2 gave the minimum values due to high flow rates observed on site. The VR value of 0.27 for the M60 Section 2 represents the critical value that causes disruption in traffic and queues start to form. However, this critical value is less than that of 0.35 recommended by the HCM (2000).

Furthermore, Table 3 indicates that the maximum value of R is mostly similar for all sites except for the Northenden site (i.e. R = 0.24). The minimum values of R are also similar for all sections except that for the Northenden site. This is due to the fact that the observed on ramp flow for this site was relatively low. Although it may appear that having a low R value does not cause traffic congestion, observation from the Northernden site at these low R values suggest that some congestion has occurred for several periods of time. This could be attributed to weaving drivers on the upstream section before the nose finding a relatively clear road ahead in the auxiliary lane (within the weaving section). This could motivate most of these drivers to change lanes very early and very close to the entrance point (nose). The process relating to these manoeuvres involves adjustment in speeds which may require deceleration. Consequently, this results in causing some turbulence within that section close to the merging point for such low values of R. Therefore, it is not always true to associate low R values with free flow conditions or with desirable operations.

Table 3 Observed values of VR and R for different sites.

Sections	Flow range veh/hr	Max VR vs. Flow		Max R vs. Flow		Min R vs. Flow	
		Max VR	Flow	Max R	Flow	Min R	Flow
Mancunian Way Site 1	1100-4050	0.58	3324	0.5	3816	0.3	2830
Mancunian Way Site 2-Section 1	2100-3350	0.48	3180	0.49	2724	0.3	3348
Mancunian Way Site 2-Section 2	2000-3000	0.55	2052	0.49	2052	0.41	2736
Northenden Section 1	2900-5000	0.58	3780	0.24	3624	0.11	4476
Northenden Section 2	4000-5600	0.51	4152	0.24	4632	0.09	4152
M60 Section 1	5000-8000	0.25	7400	0.49	7300	0.3	7000
M60 Section 2	4200-7260	0.27	7092	0.48	6768	0.33	6720

4.2.4 Effective length

In this study, the effective length represents the actual length at which almost all weaving vehicles require to finish their necessary lane changes to reach their destination lane with the weaving section. For the Mancunian Way Site 2, the effective lengths represent the whole weaving length (i.e. 150, 125m for Sections 1 and 2, respectively). Whereas, the effective length of about 200m was observed for all other ramp weave sections where the actual weaving length is equal or more than 300m.

4.2.5 Merging points

The merging point in this study represents the point at which the vehicle crosses the longitudinal pavement marking in order to change lane from its current lane to the adjacent lane. Field data consisting from 3 hours under heavy flow has been analysed to investigate the behaviour of drivers along the M60 J2 weaving section. Because the concentration of LC is in the first 200m as discussed before, so the first 200m has been divided in four zones each 50m.

The merging points can be classified into two cases: First case from lane 1 to 2 and second case from lane 2 to 1. First case is illustrated in Figure 4 which indicates that the maximum percentage of LC took place within the zone of 0-50 m. This percentage ranges from 39% to 60% under moderate to heavy level of flow. This percentage fluctuates under different level of flow. However, this zone represents the region of concentration of LC along the weaving section. The third zone has the larger values than the first and fourth zone but less than the second zone. This means the concentration of merging vehicles within the first 100m ranges from 72% to 98% from the vehicles that merging from the first lane.

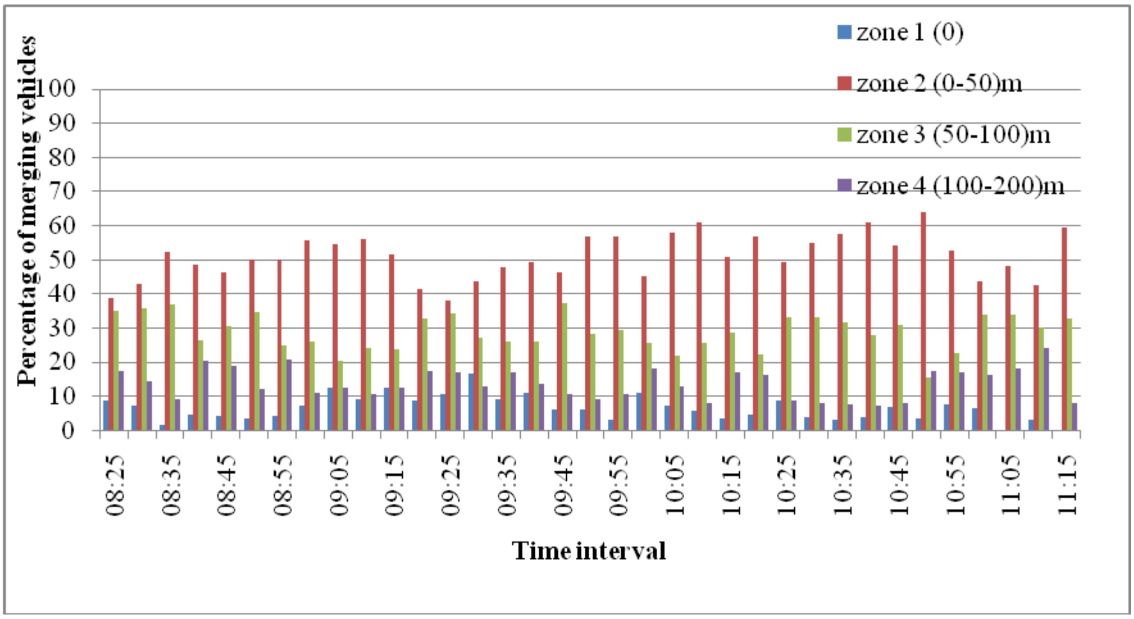


Figure 4 Percentage of FLC from lane 1 to lane 2 at different zones from weaving section length.

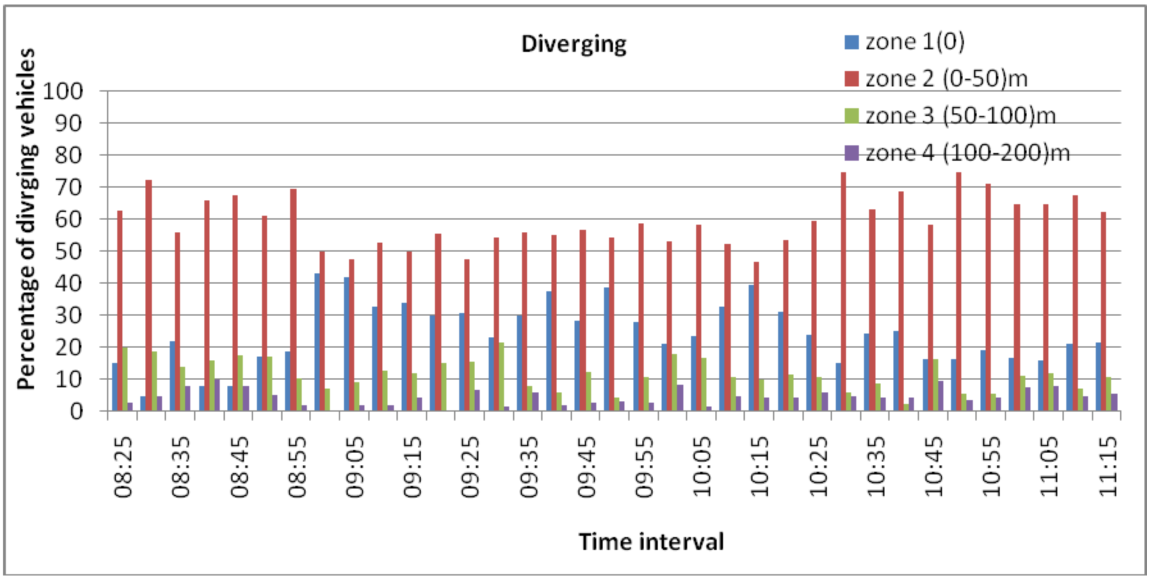


Figure 5 Percentage of FLC from lane 2 to lane 1 at different zones from weaving section length.

Figure 5 indicates the second case. The second zone here also represents the maximum percentage of concentration among other zone but with higher values than the second zone in the first case. Whereas, the values of first zone is also higher than values of the first zone in the first case by two times or more in some cases as shown in Figure 5. The concentrations of merging activities in the third and forth zones are less that for the same zones in the first case as shown in Figure 5.

In light of the above, the concentration of merging activities is within the first 50m from the weaving length which may reach 70% from all merging cases along this section. Therefore, the percentage of merging vehicles from the third and forth zones less than 50% under different level of flow as shown in Figure 4. Finally, the results obtaining from the merging points show that the behaviour of weaving vehicles can be characterised by staying on-ramp vehicles longer distance before entering motorway than motorway vehicles heading to off-ramp.

5 Conclusion and Further Research

This study describes how driver behaves at weaving sections in the UK by describing the following characteristics:

- The maximum number of lane changes observed across a single line-lane at 76m is 1500 LC/hr. This value is higher than that reported by Cassidy and May (1991) of 1200 LC/hr.
- Observations suggest that the critical value of VR for a ramp weave-four lane section is 0.27 compared with a recommended value by the HCM (2000) of 0.35.
- Observed R values revealed that as R increases, the likelihood of traffic turbulence increase. However, low R values do not necessary represent cases free from congestion.
- For ramp weave sections, the effective length of weaving section depends on the available weaving length. For short weaving lengths (i.e. below 150m) the effective length is the full weaving length. For weaving lengths in excess of 300m, the effective length is less or equal to 200m.
- The merging activities for vehicles changing lane from the on-ramp to the motorway concentrate within the first 100m from entrance point but very few activities at entrance point (zero weaving length). Whereas, the concentration of merging activities is also within the first 100m for vehicles changing lane from motorway to auxiliary lane but very few activities between 100m to 200m. These merging points have proved clearly the behaviour of weaving drivers in terms of where the manoeuvres concentrate for the selected sections.
- The upstream section of weaving area characterised by segregation weaving vehicles from non-weaving vehicles. It was found through this study that 70% or more of weaving vehicle segregate from other traffic within the 250m upstream the entrance point of weaving section.

The above investigated characteristics could be involved in developing simulation models either in a calibration or validation process. Further researches are needed to investigate the behaviour of other types of weaving section such as type B to compensate the lack of weaving data, especially in the UK.

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